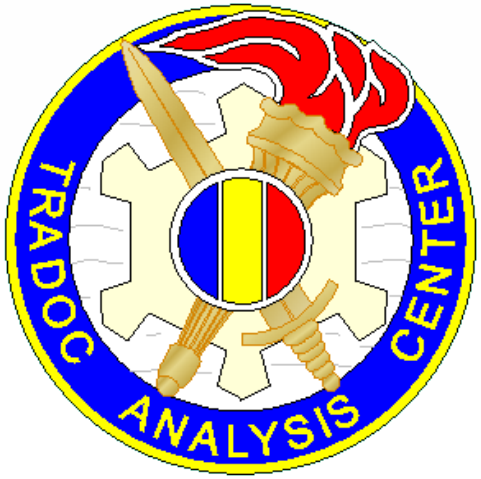
Modeling Target Acquisition, Tracking and Loss in Urban Terrain



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We are searching for the urban target acquisition modeling equivalent of P_{hit} and P_{kill} from attrition modeling.

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Problem

- **Future Combat System (FCS) & the Objective Force (OF) dependent upon**
  - **multi-sensor collection of information,**
  - **robust networks to transmit information,**
  - **rapid assimilation and understanding of information obtained from a variety of sources,**
  - **uninterrupted satisfaction of the priority information requirements of commanders and soldiers, and**

BUT…

- **Legacy systems and legacy models are inadequate to**
  - **address the C4ISR and fusion requirements of FCS/OF.**
  - **assess potential of future technologies.**
  - **address MOUT.**

Assumptions

- **The Urban Acquire physical model will effectively represent the very high resolution single sensor and single target case.**
- **Physical models like Urban Acquire do not scale to reasonable unit of action (brigade) urban scenarios due to the computational cost for hundreds of sensors and thousands of potential targets.**
- **Urban Acquire focuses on acquisition and classification, but is less useful for target tracking and loss.**
- **Data can be obtained from Urban Acquire, other physical models, experimentation, and real world sources.**

Proposal

- **We propose to model target acquisition, tracking and loss in MOUT with graphs and then apply novel analysis techniques such as those from the theory of random graphs to gain insights for the Objective Force (OF) and Future Combat System (FCS).**
- **This research builds on the Urban Acquire project and complements that effort**
  - **By providing analysis tools for OF/FCS.**
  - **By providing aggregate models for future simulations.**

Approach

- **Our models will represent target acquisition, tracking and loss for large numbers of sensors (including suites of sensors and networks of sensors) arrayed against many potential targets.**
- **Our models will deal in the aggregate with the sensors and targets providing estimates for various individual cases and estimates for total system performance.**
- **Our models rely on parameters derived from higher resolution models and data.**
- **Graph models of simple sensor target pairings are building blocks for larger graphs.**

Low Resolution Example

- **Question: How do I search for elements of a Mechanized Division hiding in a big city?**

- **Answer: Based on the UTZ description of the city, types and quantities of targets in the division, and the types and quantities of sensors at the commander's disposal, the model will recommend sensor allocation strategies and estimate the probability of target discovery within a specified timeframe.**

Medium Resolution Example

- **Question: Which individual combatants and non-combatants can I see (sense, detect, recognize, identify, etc.) right now in this sector of the city with these sensors?**
- **Example Answers**
  - **Based on information about each individual, the set of sensors, and general information about the urban area, the model will tell you the probability that you see each individual.**
  - **Based on information about the type and numbers of individuals, the set of sensors, and general information about the urban area, the model will estimate the likelihood that you see an individual in a given location.**

Background: Sensors

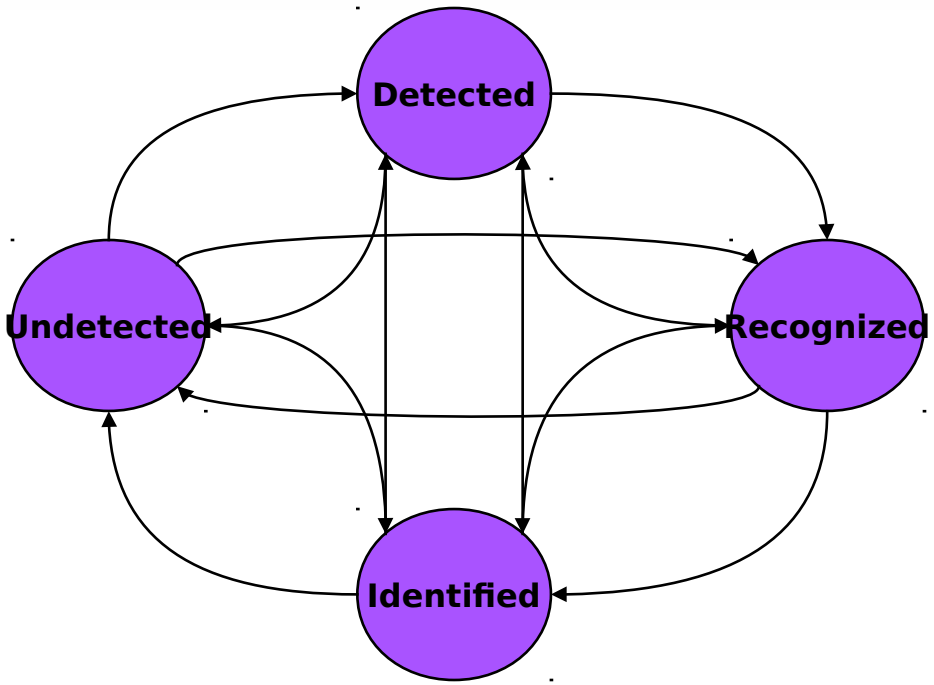
- **Definitions**
  - **Sensor: any device or human capability that detects a target.**
  - **Sensor Suite: two or more sensors acting together to detect targets.**
  - **Sensor Network: a managed set of sensors and sensor suites whose data is integrated and fused to develop a common operating picture.**
- **Potential Parameters**
  - **Type (acoustic, visual, IR, seismic, RADAR, etc.)**
  - **Performance (by range, target type, environment, etc.)**
  - **Operational characteristics (operational altitude, movement capabilities, time on station, etc.)**

Background: Graph Models

- A graph is a set of nodes and a set of arcs (pairs of nodes).
- A network is a graph having information associated with nodes or arcs.
- Of particular interest when structuring the sensor network are results related to graph structures including those about cliques and graph components.
- Our graph models rely on random processes which allows the larger models to be analyzed using techniques associated with graph theory and the theory of random graphs.

Background: Stochastic Models

- **A random process (e.g., Markov Chain)**
  - **Is represented using a graph.**
  - **Nodes represent states.**
  - **Arcs represent the probability that the system transitions between two states.**



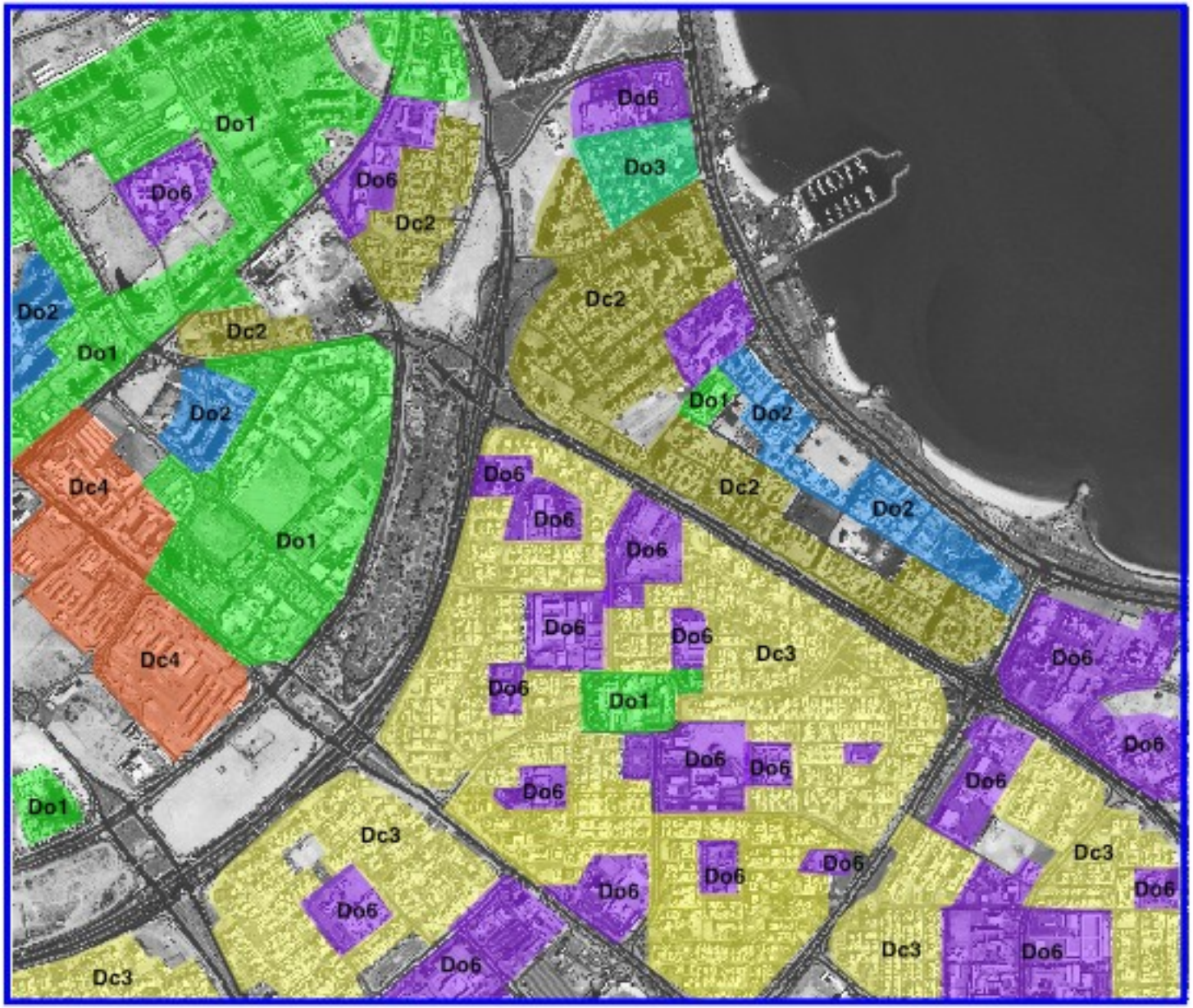
Classic state transition model, where nodes represent the state of the target with respect to all sensors or a given sensor.

Background: Random Graph Theory

- **Random Graph Theory applies methods from probability to the structure of large graphs.**
- **Methods from the theory of random graphs might allow us to make assertions about the collective effectiveness of the sensors.**
- **Example (Nodes are targets & sensors; Edges represent tracking of the target by the sensor)**
  - **There might exist a threshold probability function for edge connectivity probability that ensures information dominance.**
  - **Parameters related to edge probabilities could then be varied to examine their effect on information dominance for various quantities and types of sensors.**

Background: Urban Terrain Zones

- **Professor Ellefsen, a geographer, developed Urban terrain zones to classify areas in the urban landscape with an emphasis on the military significance of differences among areas.**
- **Typical parameters (that distinguish a UTZ)**
  - **building dimensions, spacing, construction type, street widths, set back, vegetation, etc.**
- **Examples**
  - **A1: tall buildings; city core; no spacing.**
  - **Dc3: low, closely-spaced residential buildings.**
  - **Do4: low, widely-spaced industrial/storage buildings located at the edge of cities near major highways.**



Urban Terrain Zones

A Section of Kuwait City

Model Development

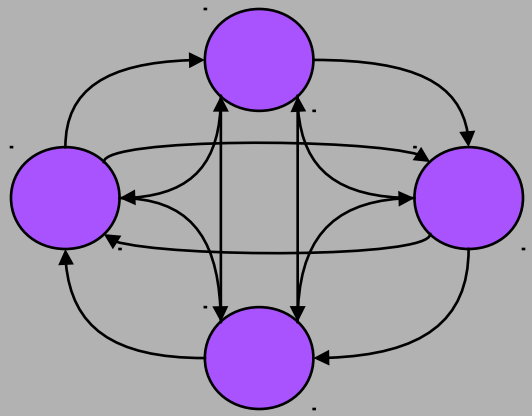
- Use simple graph models like those based on sensor- target pairings as building blocks for larger graphs.
- Consider parameter development process during the modeling stage.
- Develop questions of interest for the models to answer (these will be our use cases).
- Conduct computational experiments using simple physical models.
- Plan for validation during model development.

Method to Develop Model Parameters

1) Select a candidate model (e.g., a target state transition model).
2) Design a high resolution experiment (e.g., high resolution simulation).
3) Conduct the experiment collecting multiple sets of data (saving some data for verification).
4) Estimate the model parameters and test against out-of-sample data.
5) Generalize the high resolution data (e.g., represent the urban terrain as urban terrain zones).
6) Use statistical techniques to estimate model parameters for the general case.

Method to Generalize Terrain & Models

Generalize



Example Computational Experiment

- **Purpose - to estimate 2-D geometric inter-visibility distributions in each of the 16 UTZs.**
- **Method**
  1) **generate UTZ specific sample terrain.**
  2) **generate random (or systematic) sensor locations.**
  3) **determine the extent of geometric intervisibility in various directions.**
  4) **develop a distribution of geometric intervisibility lengths for the UTZ.**
- **Potential Use - provides a basis for determining how far a sensor might be able to see in a particular UTZ.**

Validation

- **Use model-test-model methodology.**
- **Near term**
  - **Document how the model parameters were developed.**
  - **Use geo-typical terrain, high resolution simulation, etc.**
- **Beyond 2003**
  - **Seek experimental opportunities.**
  - **Update models as high resolution models are developed and refined.**

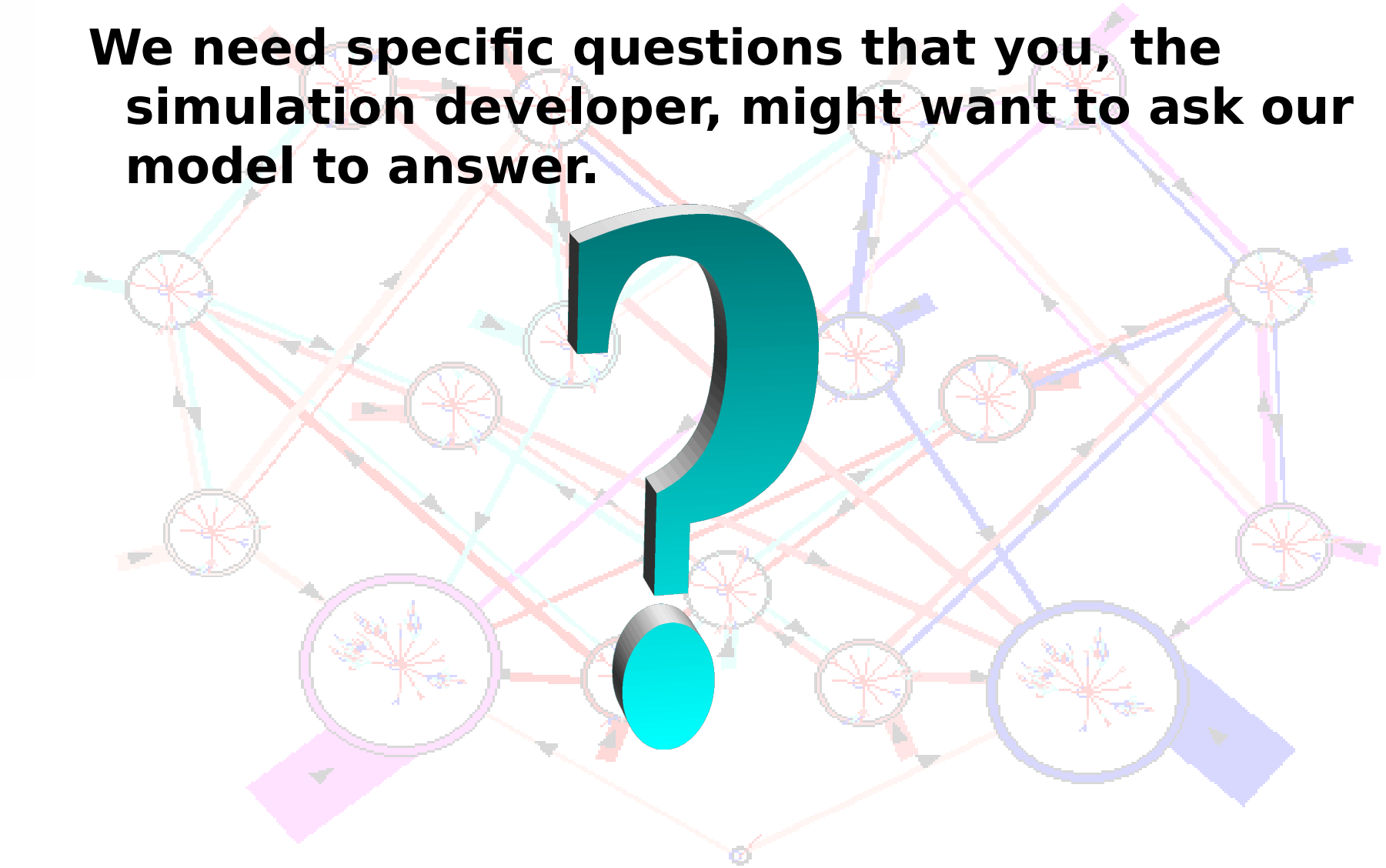
Focus

- **Our immediate focus will be on models that provide potential solutions for emerging simulations like OOS and COMBAT^{XXI}**
- **This research will evolve to support modeling and analysis for Objective Force and the Future Combat System in urban terrain.**
- **Examples**
  - **Effect of networking sensors on track loss.**
  - **Analysis of sensor density and mix required to achieve information dominance.**

The outcomes of military operations are highly correlated with target acquisition capabilities.

Discussion

We need specific questions that you, the simulation developer, might want to ask our model to answer.



Background: Example Graph